NASA Technical Memorandum 102659

EQUILIBRIUM RADIATIVE HEATING TABLES FOR AEROBRAKING IN THE MARTIAN ATMOSPHERE

Lin C. Hartung

Kenneth Sutton

Frank Brauns

(NASA-TM-102659) EQUILIBRIUM RADIATIVE HEATING TABLES FOR AEROBRAKING IN THE MARTIAN ATMOSPHERE (NASA) 20 p CSCL 20D

N90-25290

Unclas

G3/34 0290739

May 1990

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

EQUILIBRIUM RADIATIVE HEATING TABLES FOR AEROBRAKING IN THE MARTIAN ATMOSPHERE

Lin C. Hartung
Kenneth Sutton

NASA Langley Research Center
Hampton, VA 23665

Frank Brauns

North Carolina State University

Introduction

Studies currently underway for Mars missions often envision the use of aerobraking for orbital capture at Mars. These missions generally involve blunt-nosed vehicles to dissipate the excess energy of the interplanetary transfer. Radiative heating may be of importance in these blunt-body flows because of the highly energetic shock layer around the blunt nose. In addition, the Martian atmosphere contains CO_2, whose dissociation products are known to include strong radiators.

Sutton[1] developed an inviscid, equilibrium, stagnation point, radiation-coupled flow-field code for investigating blunt-body atmospheric entry. The method has been compared with ground-based and flight data for air,[2] and reasonable agreement has been found. In the present work, the method has been applied to a matrix of conditions in the Martian atmosphere. These conditions encompass most trajectories of interest for Mars exploration spacecraft. The predicted equilibrium radiative heating to the stagnation point of the vehicle is presented here.

Method

The method used is the Radiating, Inviscid Flow, Stagnation Point (RIFSP) code. Details of the method, which is essentially a solution of the radiation-coupled inviscid flow equations at a hemispherical stagnation point, can be found in Sutton.[1] The radiation model is the equilibrium radiation line group method developed by Nicolet,[3] which includes atomic line and continuum mechanisms, as well as molecular bands. The RIFSP code was recently updated to FORTRAN V, and its overlay structure was removed in the process. It runs easily on current computers and requires less than 3 seconds of CPU time per iteration on a Sun4 SPARCstation, even for the most difficult iteration cases discussed below. The cases in this paper generally converged in less than 1000 iterations depending on the magnitude of the radiative flux. Memory size is no longer a concern for this code with current computers.

Calculation Matrix

The matrix of velocity and density conditions for which solutions have been obtained was generated by attempting to bracket the flight conditions of most Mars aerobraking vehicles that are currently envisioned. Walberg[4] gives an overview of the mission scenarios, while Braun[5] provides a detailed study. A matrix of the selected conditions is given in Figure 1. A series of body shapes was also considered at each flight condition to bracket the vehicle designs under consideration. These range from a moderate nose radius of 1-m to a very blunt body with a 23-m nose radius.

All computations were made using an assumed atmospheric composition of 97-percent CO_2 and 3-percent N_2. If argon is also present in the atmosphere, it can have a significant impact on the radiative heating by reducing the amount of energy which goes into dissociation. The amount of argon present in the Martian atmosphere is somewhat controversial, so this effect has not been considered in the present study.

Results

The equilibrium radiative heating results obtained for the Mars entry matrix are given in Tables 1-9 for free-stream densities ρ_∞ ranging from 3.162e-8 to 1.e-2 kg/m^3. Each table includes the entry velocity V in km/s, the nose radius R_n in meters, and the radiative heating rate Q_r in MW/m^2. The results are also plotted in Figures 2-10 and show the variation of the logarithm of radiative heating with the logarithm of the nose radius for various velocities at each free-stream density.

Discussion

The results display the expected trends of increasing radiative heating with increasing nose radius or entry velocity. All cases in the matrix have been run with 20 grid points along the stagnation line. This was found to be adequate in a previous study of Earth entry radiative heating.[6] In a small fraction of the cases a slight readjustment in the distribution of the grid points was necessary. This necessity occurred with no discernable pattern for about 8 percent of the cases, all with relatively minimal radiative heating. The adjustment was required by a breakdown in the iteration procedure which is thought to be caused by the sensitivity of the chemistry iteration at certain conditions. The adjustment of the grid points should have minimal effect on the results. In previous work, an impact was observed when changing the number of grid points, but not when making minor readjustments in a sufficiently resolved grid.

Note that this is strictly an equilibrium method. Nonequilibrium effects, which may be important in some of these cases, have been completely ignored. Also, since the method is inviscid, the potential absorption of radiation by a boundary layer has been neglected.

If an ablating heat shield is necessary, as some studies have indicated,[5] the presence of ablation products may significantly alter the radiative heating to the wall. The current results may be regarded as conservative estimates in that situation.

Conclusion

A matrix of equilibrium radiative heating results has been generated for Mars aerobraking in an assumed 97-percent CO_2, 3-percent N_2 atmosphere. These results have been presented in tabular and graphical form for use in design and parametric studies.

References

1. Sutton, Kenneth, ''Characteristics of Coupled Nongray Radiating Gas Flows with Ablation Products Effects About Blunt Bodies During Planetary Entries,'' PhD Thesis, North Carolina State University, Raleigh, North Carolina, 1973.
2. Sutton, Kenneth, ''Air Radiation Revisited,'' in *Progress in Astronautics and Aeronautics: Thermal Design of Aeroassisted Orbital Transfer Vehicles*, ed. H.F. Nelson, vol. 96, pp. 419-441, AIAA, New York, 1985.
3. Nicolet, W. E., ''Advanced Methods for Calculating Radiation Transport in Ablation-Product Contaminated Boundary Layers,'' NASA CR-1656, Sept. 1970.
4. Walberg, Gerald D., ''A Review of Aerobraking for Mars Missions,'' IAF Paper 88-196, October 1988.
5. Braun, Robert D., Richard W. Powell, and Lin C. Hartung, ''The Effect of Interplanetary Trajectory Options on a Manned Mars Aerobrake Configuration,'' NASA TP-3019, 1990.
6. Sutton, Kenneth and Lin C. Hartung, ''Equilibrium Radiative Heating Tables for Earth Entry,'' NASA TM-102652, 1990.

Table 1. Radiative Heating Prediction for $\rho_\infty = 1.E{-2}\ kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
5.0	1.0	4.434E-3
	2.3	8.605E-3
	5.0	1.521E-2
	10.0	2.419E-2
	23.0	4.090E-2
6.0	1.0	.1080
	2.3	.1987
	5.0	.3450
	10.0	.5620
	23.0	.9787
7.0	1.0	6.551
	2.3	11.010
	5.0	17.846
	10.0	26.425
	23.0	38.793

Table 2. Radiative Heating Prediction for $\rho_\infty = 3.162E{-3}\ kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
5.0	1.0	5.668E-4
	2.3	1.185E-3
	5.0	2.280E-3
	10.0	3.972E-3
	23.0	7.336E-3
6.0	1.0	2.342E-2
	2.3	4.238E-2
	5.0	7.595E-2
	10.0	1.261E-1
	23.0	2.292E-1
7.0	1.0	1.700
	2.3	2.862
	5.0	4.581
	10.0	6.901
	23.0	11.431

Table 3. Radiative Heating Prediction for $\rho_\infty = 1.E{-3}\ kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
5.0	1.0	6.569E-5
	2.3	1.429E-4
	5.0	2.914E-4
	10.0	5.390E-4
	23.0	1.094E-3
6.0	1.0	7.944E-3
	2.3	1.215E-2
	5.0	1.985E-2
	10.0	3.288E-2
	23.0	6.141E-2
7.0	1.0	4.558E-1
	2.3	7.076E-1
	5.0	1.147
	10.0	1.737
	23.0	2.837

Table 4. Radiative Heating Prediction for $\rho_\infty = 3.162E{-4}\ kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
4.0	1.0	3.645E-7
	2.3	8.279E-7
	5.0	1.768E-6
	10.0	3.640E-6
	23.0	7.647E-6
5.0	1.0	7.245E-6
	2.3	1.609E-5
	5.0	3.365E-5
	10.0	6.458E-5
	23.0	1.393E-4
6.0	1.0	3.072E-3
	2.3	4.986E-3
	5.0	7.322E-3
	10.0	1.068E-2
	23.0	1.870E-2
7.0	1.0	1.316E-1
	2.3	1.968E-1
	5.0	2.842E-1
	10.0	4.171E-1
	23.0	6.870E-1
8.0	1.0	3.343E-1
	2.3	5.062E-1
	5.0	7.026E-1
	10.0	9.788E-1
	23.0	1.578
9.0	1.0	6.111E-1
	2.3	9.889E-1
	5.0	1.334
	10.0	1.734
	23.0	2.630

Table 5. Radiative Heating Prediction for $\rho_\infty = 1.E{-4}\ kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
4.0	1.0	4.355E-8
	2.3	9.971E-8
	5.0	2.152E-7
	10.0	4.262E-7
	23.0	9.638E-7
5.0	1.0	7.720E-7
	2.3	1.746E-6
	5.0	3.714E-6
	10.0	7.235E-6
	23.0	1.606E-5
6.0	1.0	
	2.3	1.841E-3
	5.0	3.028E-3
	10.0	4.417E-3
	23.0	6.791E-3
7.0	1.0	3.037E-2
	2.3	5.303E-2
	5.0	8.112E-2
	10.0	1.118E-1
	23.0	1.641E-1
8.0	1.0	7.194E-2
	2.3	1.295E-1
	5.0	1.998E-1
	10.0	2.667E-1
	23.0	3.771E-1
9.0	1.0	1.159E-1
	2.3	2.280E-1
	5.0	3.732E-1
	10.0	5.090E-1
	23.0	6.821E-1

Table 6. Radiative Heating Prediction for $\rho_\infty = 3.162E-5\,kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
4.0	1.0	5.171E-9
	2.3	1.187E-8
	5.0	2.576E-8
	10.0	5.130E-8
	23.0	1.172E-7
5.0	1.0	8.107E-8
	2.3	1.851E-7
	5.0	3.988E-7
	10.0	7.877E-7
	23.0	1.774E-6
6.0	1.0	2.704E-4
	2.3	5.516E-4
	5.0	1.001E-3
	10.0	1.625E-3
	23.0	2.707E-3
7.0	1.0	5.500E-3
	2.3	1.113E-2
	5.0	1.972E-2
	10.0	3.049E-2
	23.0	4.611E-2
8.0	1.0	1.219E-2
	2.3	2.535E-2
	5.0	4.619E-2
	10.0	7.183E-2
	23.0	1.068E-1
9.0	1.0	1.800E-2
	2.3	3.926E-2
	5.0	7.699E-2
	10.0	1.270E-1
	23.0	1.976E-1
10.0	1.0	3.112E-2
	2.3	5.783E-2
	5.0	1.005E-1
	10.0	1.675E-1
	23.0	3.030E-1

Table 7. Radiative Heating Prediction for $\rho_\infty = 1.E-5\,kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
4.0	1.0	6.155E-10
	2.3	1.415E-9
	5.0	3.075E-9
	10.0	6.142E-9
	23.0	1.409E-8
5.0	1.0	8.516E-9
	2.3	1.955E-8
	5.0	4.235E-8
	10.0	8.429E-8
	23.0	1.921E-7
6.0	1.0	6.145E-5
	2.3	1.350E-4
	5.0	2.694E-4
	10.0	4.743E-4
	23.0	8.804E-4
7.0	1.0	8.633E-4
	2.3	1.897E-3
	5.0	3.783E-3
	10.0	6.616E-3
	23.0	1.184E-2
8.0	1.0	1.823E-3
	2.3	4.054E-3
	5.0	8.248E-3
	10.0	1.477E-2
	23.0	2.653E-2
9.0	1.0	2.570E-3
	2.3	5.814E-3
	5.0	1.225E-2
	10.0	2.313E-2
	23.0	4.507E-2
10.0	1.0	4.660E-3
	2.3	9.326E-3
	5.0	1.736E-2
	10.0	2.953E-2
	23.0	5.576E-2

Table 8. Radiative Heating Prediction for $\rho_\infty = 3.162E-6\ kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
4.0	1.0	7.364E-11
	2.3	1.693E-10
	5.0	3.681E-10
	10.0	7.362E-10
	23.0	1.691E-9
5.0	1.0	9.028E-10
	2.3	2.075E-9
	5.0	4.506E-9
	10.0	9.000E-9
	23.0	2.064E-8
6.0	1.0	1.268E-5
	2.3	2.870E-5
	5.0	6.045E-5
	10.0	1.145E-4
	23.0	2.343E-4
7.0	1.0	1.286E-4
	2.3	2.915E-4
	5.0	6.154E-4
	10.0	1.169E-3
	23.0	2.389E-3
8.0	1.0	2.603E-4
	2.3	5.925E-4
	5.0	1.261E-3
	10.0	2.427E-3
	23.0	5.088E-3
9.0	1.0	3.552E-4
	2.3	8.125E-4
	5.0	1.751E-3
	10.0	3.446E-3
	23.0	7.600E-3
10.0	1.0	6.150E-4
	2.3	1.276E-3
	5.0	2.503E-3
	10.0	4.484E-3
	23.0	8.752E-3

Table 9. Radiative Heating Prediction for $\rho_\infty = 3.162E-8\ kg/m^3$

V, km/s	R_n, m	Q_r, MW/m^2
4.0	1.0	1.638E-14
	2.3	3.412E-14
	5.0	8.188E-14
	10.0	1.638E-13
	23.0	3.766E-13
6.0	1.0	1.681E-8
	2.3	3.865E-8
	5.0	8.401E-8
	10.0	1.678E-7
	23.0	3.851E-7
8.0	1.0	1.099E-7
	2.3	2.527E-7
	5.0	5.491E-7
	10.0	1.098E-6
	23.0	2.524E-6
10.0	1.0	1.423E-7
	2.3	3.147E-7
	5.0	6.593E-7
	10.0	1.279E-6
	23.0	2.849E-6

ρ_∞, kg/m^3 \ V_∞, km/s	4.0	5.0	6.0	7.0	8.0	9.0	10.0
1.000E-2		✔	✔	✔			
3.162E-3		✔	✔	✔			
1,000E-3		✔	✔	✔			
3.162E-4	✔	✔	✔	✔	✔	✔	
1.000E-4	✔	✔	✔	✔	✔	✔	
3.162E-5	✔	✔	✔	✔	✔	✔	✔
1,000E-5	✔	✔	✔	✔	✔	✔	✔
3.162E-6	✔	✔	✔	✔	✔	✔	✔
3.162E-8	✔		✔		✔		✔

Figure 1. Flight Conditions Selected for Radiation Calculations.

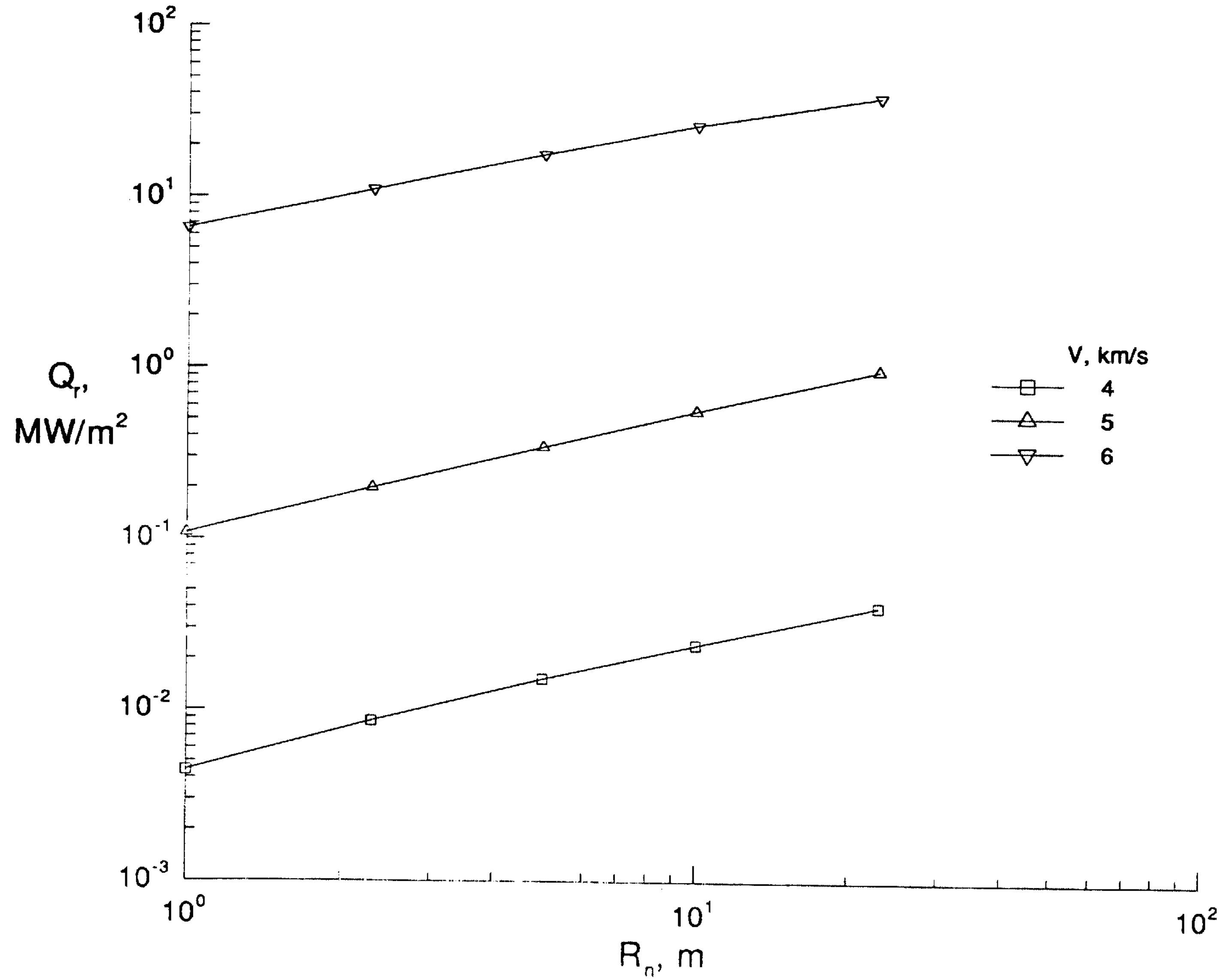

Figure 2. Radiative Heating Prediction for ρ_∞=1.E-2 kg/m^3

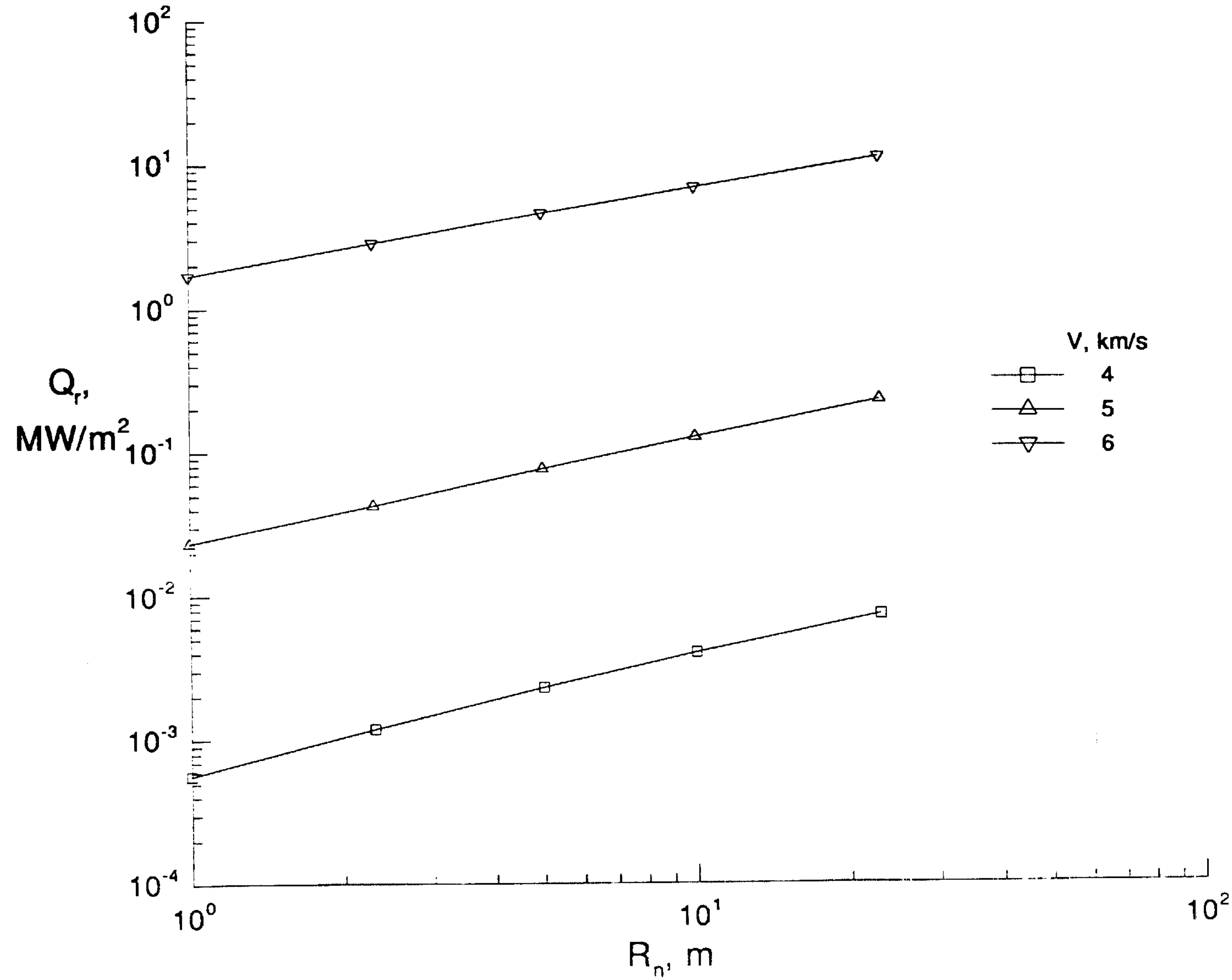

Figure 3. Radiative Heating Prediction for ρ_∞=3.162E-3 kg/m^3

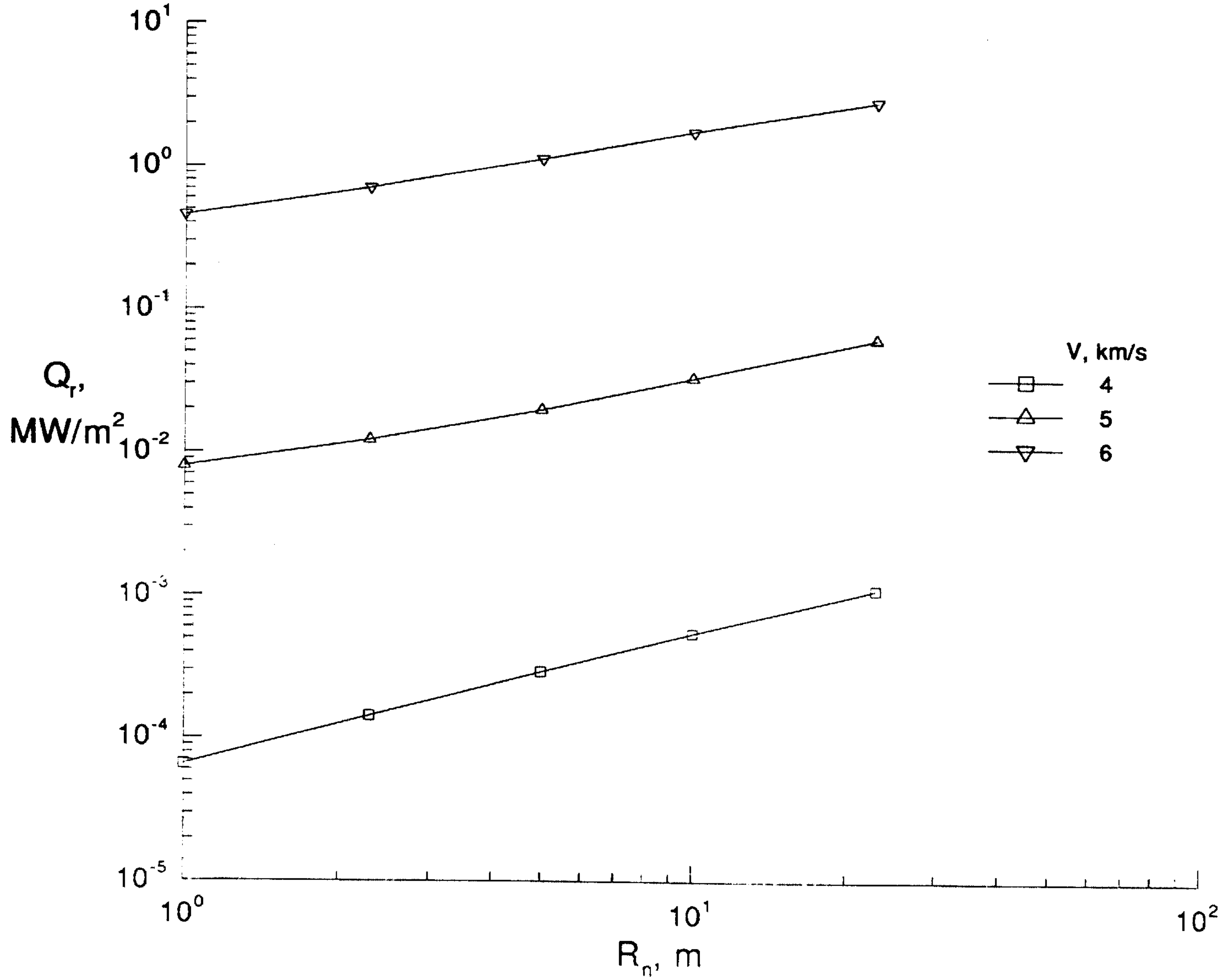

Figure 4. Radiative Heating Prediction for ρ_∞=1.E-3 kg/m^3

ORIGINAL PAGE IS
OF POOR QUALITY

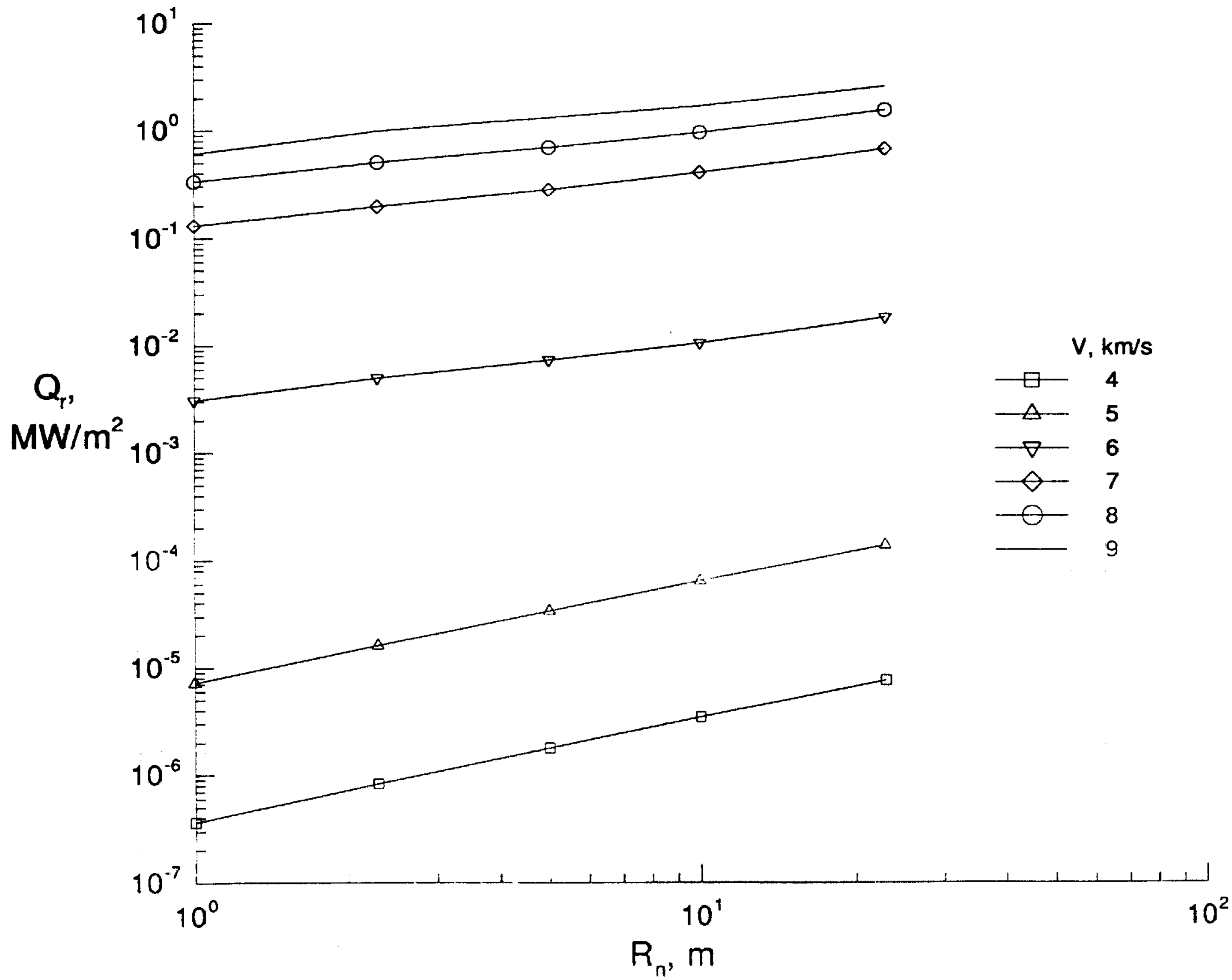

Figure 5. Radiative Heating Prediction for ρ_∞=3.162E-4 kg/m^3

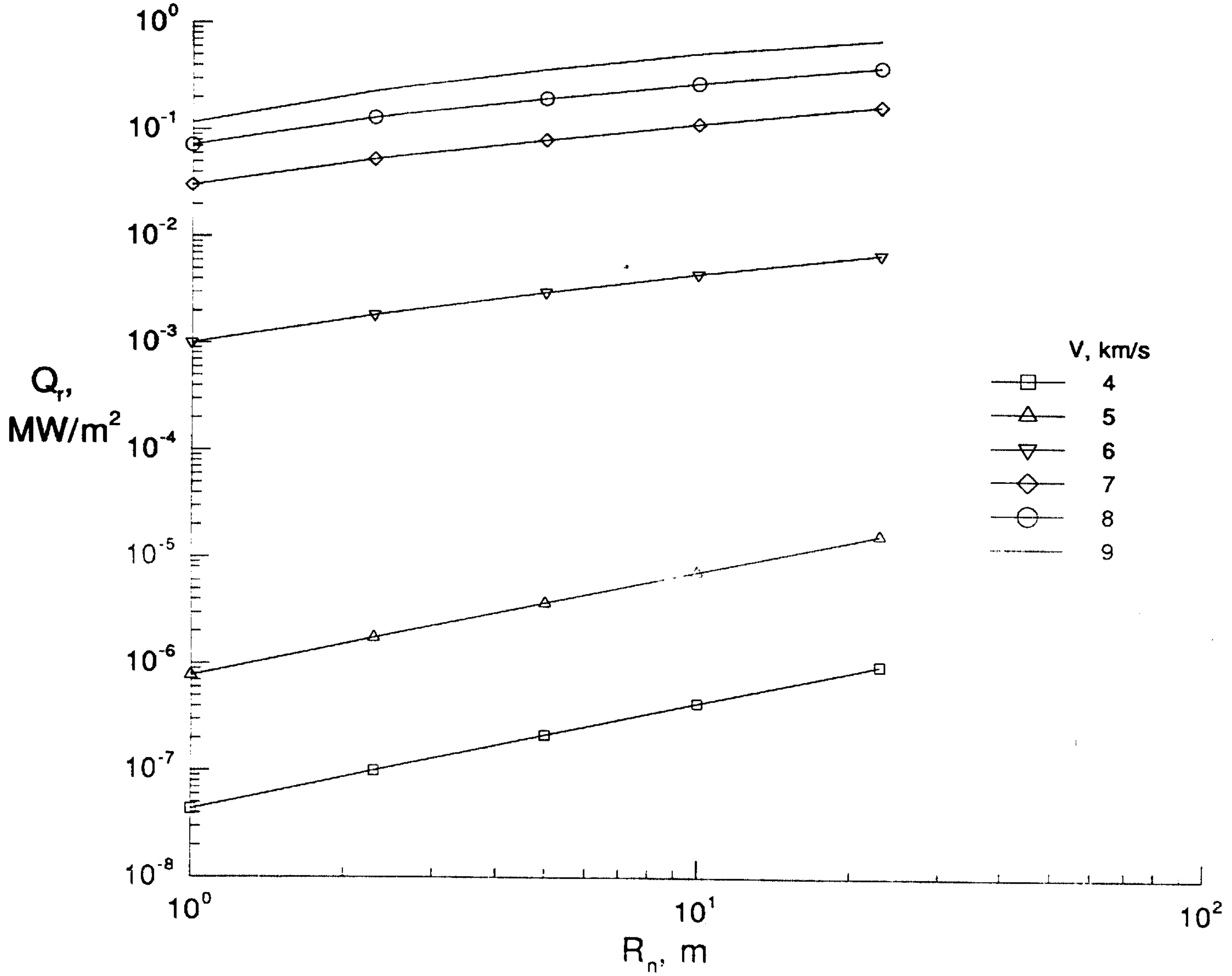

Figure 6. Radiative Heating Prediction for ρ_{∞}=1.E-4 kg/m^3

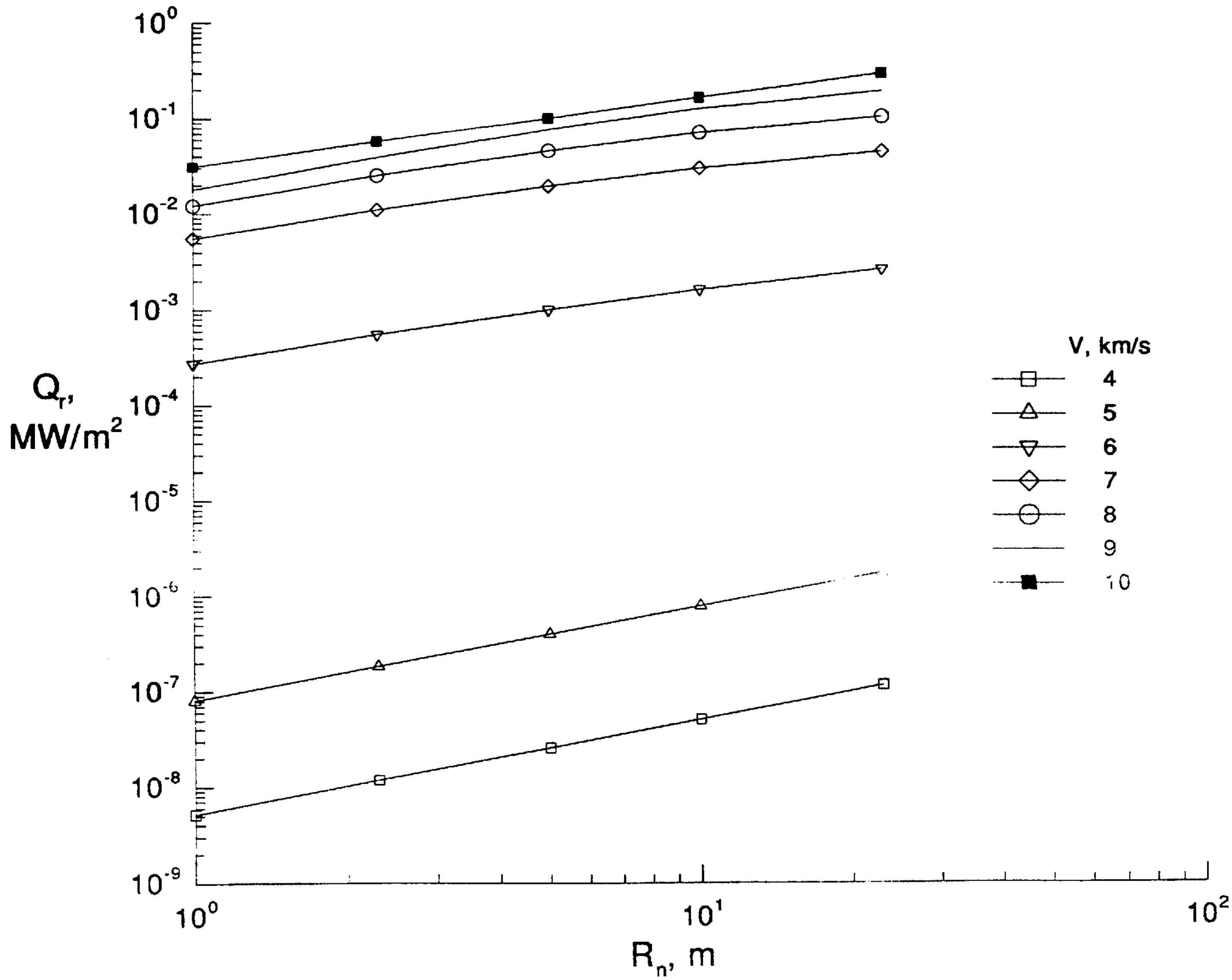

Figure 7. Radiative Heating Prediction for ρ_∞=3.162E-5 kg/m^3

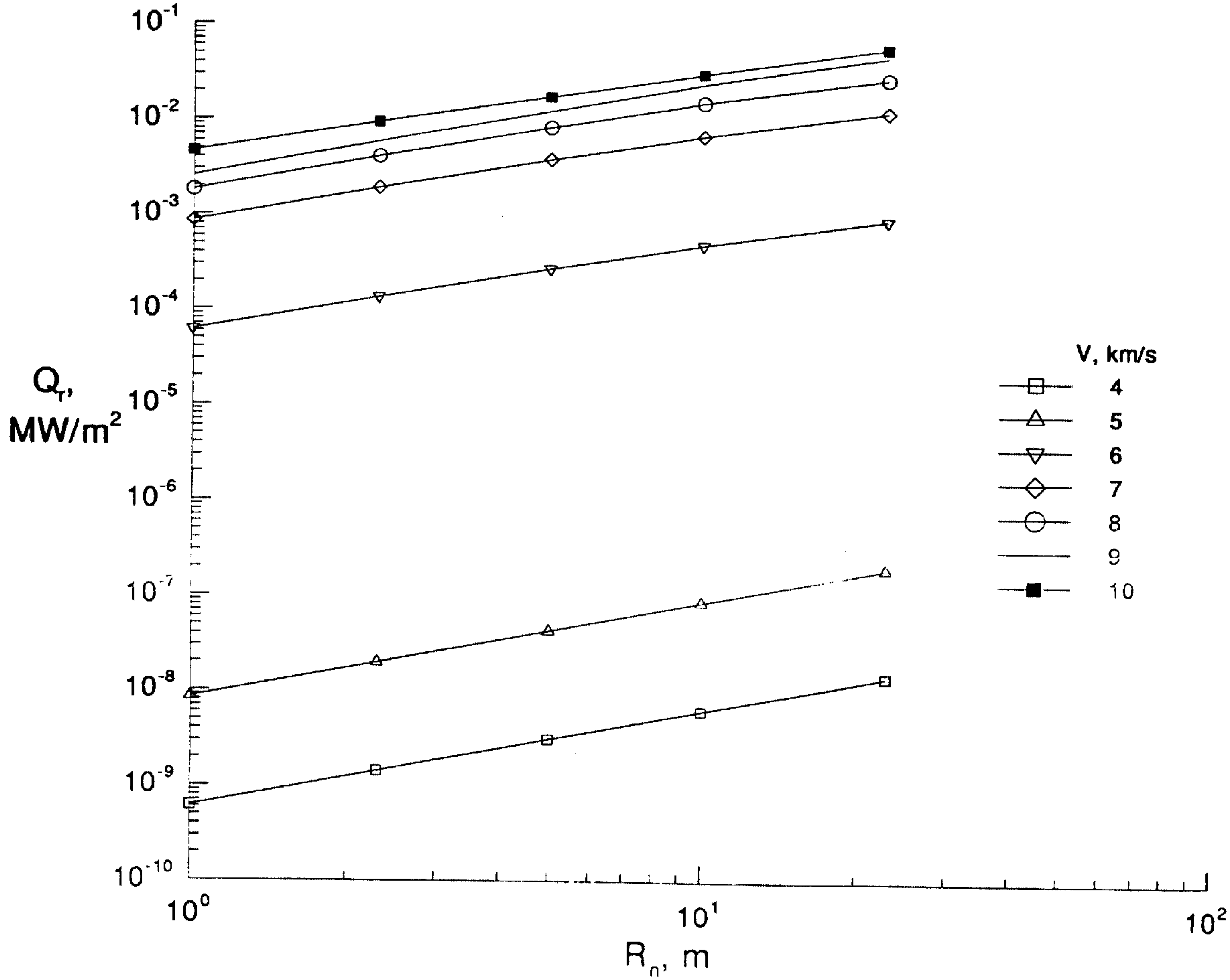

Figure 8. Radiative Heating Prediction for ρ_∞=1.E-5 kg/m^3

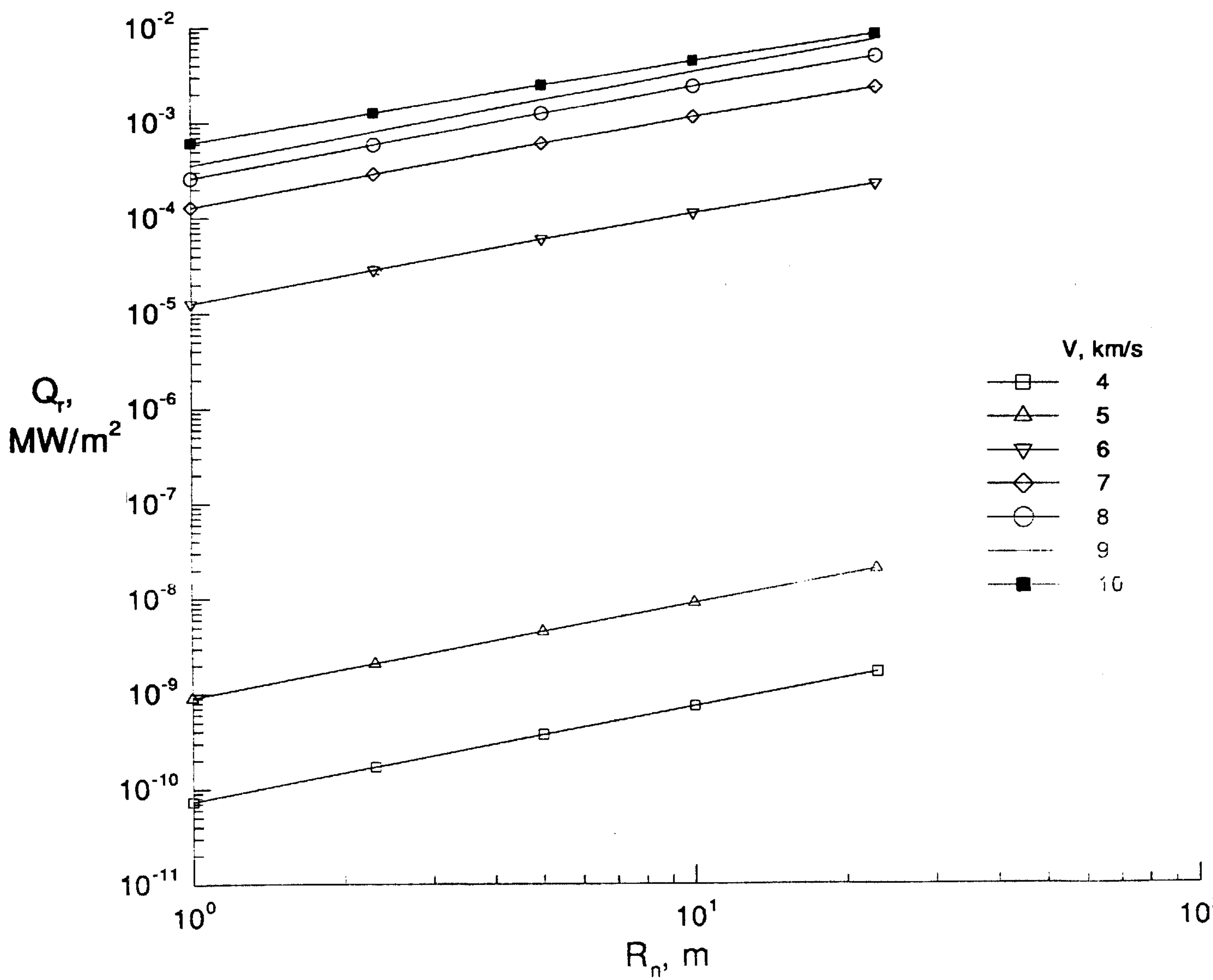

Figure 9. Radiative Heating Prediction for ρ_∞=3.162E-6 kg/m^3

ORIGINAL PAGE IS
OF POOR QUALITY

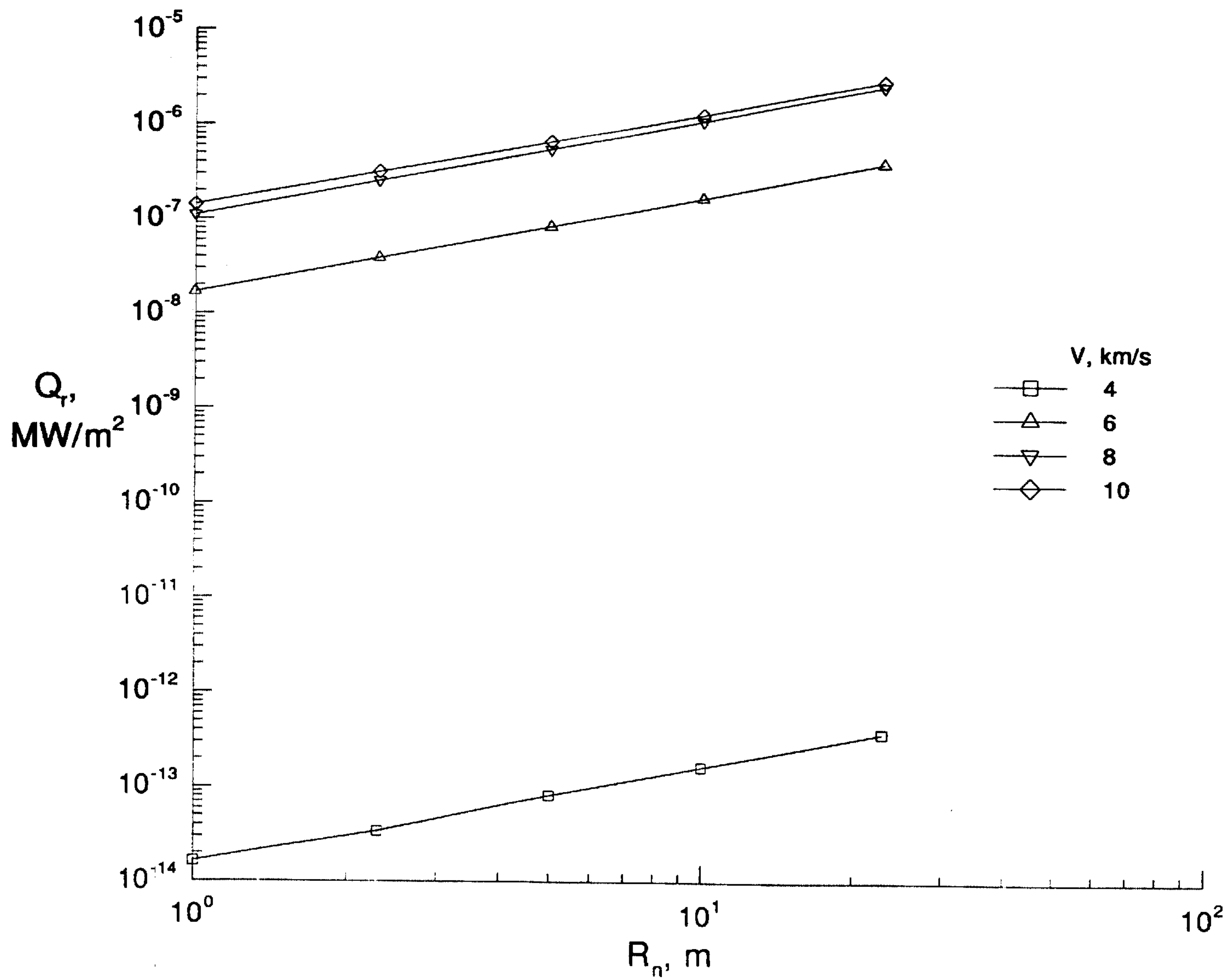

Figure 10. Radiative Heating Prediction for ρ_∞=3.162E-8 kg/m^3

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-102659		

4. Title and Subtitle	5. Report Date
Equilibrium Radiative Heating Tables for Aerobraking in the Martian Atmosphere	May 1990
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Lin C. Hartung, Kenneth Sutton, and Frank Brauns	
	10. Work Unit No. 591-42-21-01

9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, VA 23665-5225	

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Aeronautics and Space Administration Washington, DC 20546	Technical Memorandum
	14. Sponsoring Agency Code

15. Supplementary Notes

Lin C. Hartung and Kenneth Sutton: Langley Research Center, Hampton, Virginia.
Frank Brauns: North Carolina State University, Raleigh, North Carolina.

16. Abstract

Studies currently underway for Mars missions often envision the use of aerobraking for orbital capture at Mars. These missions generally involve blunt-nosed vehicles to dissipate the excess energy of the interplanetary transfer. Radiative heating may be of importance in these blunt-body flows because of the highly energetic shock layer around the blunt nose. In addition, the Martian atmosphere contains CO_2, whose dissociation products are known to include strong radiators.

Sutton developed an inviscid, equilibrium, stagnation point, radiation-coupled flow-field code for investigating blunt-body atmospheric entry. The method has been compared with ground-based and flight data for air, and reasonable agreement has been found. In the present work, the method has been applied to a matrix of conditions in the Martian atmosphere. These conditions encompass most trajectories of interest for Mars exploration spacecraft. The predicted equilibrium radiative heating to the stagnation point of the vehicle is presented here.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Martian entry Radiative heating Equilibrium	Unclassified-Unlimited Subject Category 34

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	19	A03

NASA FORM 1626 OCT 86